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THESIS

MATERIAL ASSIGNMENT AND ALLOCATION DECISIONS FOR FORWARD AND RESERVE WAREHOUSES

by

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June, 1996

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We show how to determine which material, allocated in what quantities, should be assigned to the forward and reserve warehouses. We use material data collected from Defense Distribution Depot, San Diego and apply four decision strategies to determine the allocation: Assign Similar Material Together, Assign by Popularity, Equal Time Supply, and Economic Assignment Quotient. The results show that material assignment and allocation decisions should consider the picking activity and physical characteristics of each item, as well as the length of time the forward-reserve configuration exists.

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MATERIAL ASSIGNMENT AND ALLOCATION DECISIONS FOR FORWARD AND RESERVE WAREHOUSES

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I. INTRODUCTION

A. BACKGROUND

The Defense Logistics Agency (DLA) completed its consolidation of distribution management for the Department of Defense (DoD) in 1992, when it took control of all 26 Defense Distribution Depots. Since that time, DLA's vision has been to "strive to leverage resources against global logistics targets by finding savings through better business practices, and by capitalizing on technological breakthroughs. This is not a 'future vision'. It drives everything [DLA does] today."(Chamberlin, 1994)

The business of the 26 distribution depots within the physical distribution system is not only to provide daily distribution services for material (this involves approximately 37 million transactions yearly), but also to store of $99 billion of DoD material. The 218.8 million cubic feet of warehouse space that this material commands presents the challenge for the material item managers to ensure that material is available to the operating forces when and where needed by positioning items at designated Defense Distribution Depots (GAO/NSIAD-95-64, 1995, p.3).

1. Trends in DOD Warehousing

The warehousing challenge is exacerbated at the depot level by the recent trends of downsizing, declining military budgets, and BRAC (Base Realignment and Closure Act), as well as DLA's emphasis on operating "faster, better, cheaper". Additionally, the entire

physical distribution system infrastructure is decaying. Many of the Defense Distribution Depot warehouses have existed since World War II and are now well past the end of their useful lifecycle.

The downsizing of DoD has had a dramatic effect on depot warehousing. Four depots - Charleston, Pensacola, Oakland, and Toole - will be closed under BRAC. Four other depots (Letterkenny, Memphis, Ogden, and Red River) have been recommended for closure by the Secretary of Defense (GAO/NSIAD-95-64, 1995, p.2). As these depots close, DLA must assign the material to other depots within the system. As they absorb the material from closed operations, the remaining depots will have to make more effective use of available storage space; and they will have to be more productive.

Other ripple effects from downsizing have an impact on the already strained ability of the distribution system to store material. For example, because of a slower operating tempo, demand for material with an existing stock in the supply system will decline and the material on hand will "sit on the shelf" much longer. Additionally, as more and more units and forces deactivate, material turned in to the distribution depot system will increase, creating even greater need for storage space.

2. Importance of Material Assignment Decisions

Prior to the recent upheavals in the distribution system, many DoD depot managers had been isolated from the kind of situations that require more difficult material assignment decisions. The large DoD physical distribution infrastructure allowed depot managers to make material assignment decisions "one

SKU* at a time," on an *incremental* basis and avoid many major rewarehousings†. For example, the material assignment decisions associated with the opening of a new warehouse are much different from the day-to-day material assignment decisions for material to be stowed within an existing warehouse plan. Unfortunately the more common type of material assignment decision does not normally utilize a systems perspective, which consider all of the elements of a distribution center and associated costs for space management.

DoD warehousing trends are requiring an increasing number of material assignment decisions for a much larger group of SKU's. Examples include:

- moving to a new location,
- standing up a new distribution center,
- a major rewarehousing,
- constructing new warehouses, and
- vacating existing warehouses.

The challenge faced by managers is that large-scale material assignment must incorporate many different warehouse components and fully integrate them into the physical distribution process.

3. Order Picking Opportunities

Substantial savings opportunities exist from the more efficient use of available storage space in a warehouse. Although

* Stock keeping unit (SKU) is an individual item separately identified and tracked through the warehouse (i.e. line item).

† Rewarehousing is the controlled movement of material from one location on a facility to another location on the same facility.

savings vary by industry type, it is possible to increase space utilization by 15 percent to 30 percent (Warrender, 1994).

One possible solution for some distribution centers is to buy automated equipment to support warehouse operations such as an automated storage and retrieval systems (AS/RS). Such equipment can greatly reduce picking time and costs per pick, but requires a large up-front capital expenditure.

A recent survey of warehousing professionals identified order picking as the warehousing activity most in need of engineering and management attention (Frazelle and Hackman, 1994, p.43). There are two reasons for concern: First, order picking is the most costly activity in a typical warehouse. Studies indicate 55% to 65% of the total operating costs and 50% of work force requirements can be attributed to order picking (WERC, 1986). Second, new distribution policies including logistics cycle time reduction, quick response, and just-in-time have increased the demands on the order-picking activity.

The Defense Logistics Agency's target for depot logistics response time (as measured by the Material Release Order Processing Time) continues to tighten each year, as shown in Table 1 (Performance Plan, 1996). As depot managers are forced to process material with faster throughput, time savings are sought in activities such as order picking.

	FY 95	FY 96	FY 97
Hi Priority	2 Days	1 Day	1 Day
Routine	5 Days	4.5 Days	4 Days

Table 1 - Trend in Depot Processing Time

Depot managers have no authority over which items they can store and which items they can dispose of. Wholesale inventory managers have visibility of all DoD material and make assignment and disposal decisions at the national level (Inventory Management, 1991, p.14). Individual depot managers *do*, however, have the opportunity to make material assignment and allocation decisions within their distribution centers, and these decisions can have a significant effect on the efficiency and effectiveness of order picking and the overall distribution operation.

B. STOCKING CHALLENGES FOR MULTIPLE WAREHOUSE DEPOTS

Today's Defense Distribution Depot managers are looking for ways to increase productivity without increasing staffing or making costly investments in highly automated equipment. When a distribution depot has several warehouses, choosing the proper material mix at each warehouse poses an opportunity for managers to increase throughput without raising costs.

1. The Material Assignment Decision

Depot managers with multiple warehouses must decide among several warehouses where to locate each SKU. For most managers, this decision is made at the time of receipt, based on the existing infrastructure and layout of the depot complex. For example, paper and medical supplies may be assigned to a particular warehouse because of either the demand stream (i.e. demands arrive in bunches requesting many like items) or convenience of stowage. Some SKUs are assigned to warehouses arbitrarily.

2. The Material Allocation Decision

Along with the warehouse assignment decision, distribution depot managers must decide how much space in a particular warehouse to allocate to each SKU. Some of the issues that are involved with this decision include:

- Should similar SKUs be grouped together or should they have multiple locations?
- Should all National Stock Numbers (NSNs) be grouped together?
- Should locations within the warehouse be dedicated to specific SKUs or should they be randomly allocated?
- How many warehouses are needed?
- What costs are involved with the decision?
- How might the assignment affect depot throughput?

As the demand for warehouse space increases at the Defense Distribution Depots, the assignment-allocation decision becomes more important.

C. ISSUES LEADING TO THIS STUDY

An upcoming major material rewarehousing at Defense Distribution Depot, San Diego (DDDC) provides the opportunity to use material data in the application of several strategies for material assignment and allocation decisions between warehouses.

1. Old Facilities at Distribution Depot in San Diego

Defense Distribution Depot, San Diego (DDDC) presently has six WW II era warehouses that are structurally and functionally inadequate (buildings #63, #64, #65, #68, #69, #70 in Figure 1). A MILCON* project is scheduled for the construction of one new general purpose warehouse facility to replace the six old warehouses (Depot Storage Plan, 1995).

The construction project consists of two phases. Phase I consists of demolishing three of the old warehouses (buildings #68, #69, #70) and constructing half of the new warehouse (see Figure 2). Phase II consists of demolishing the final three old warehouses (buildings #63, #64, #65) and completing the other half of the new warehouse.

* MILCON (military construction) FY 97 DDDC-01 General Purpose Warehouse.

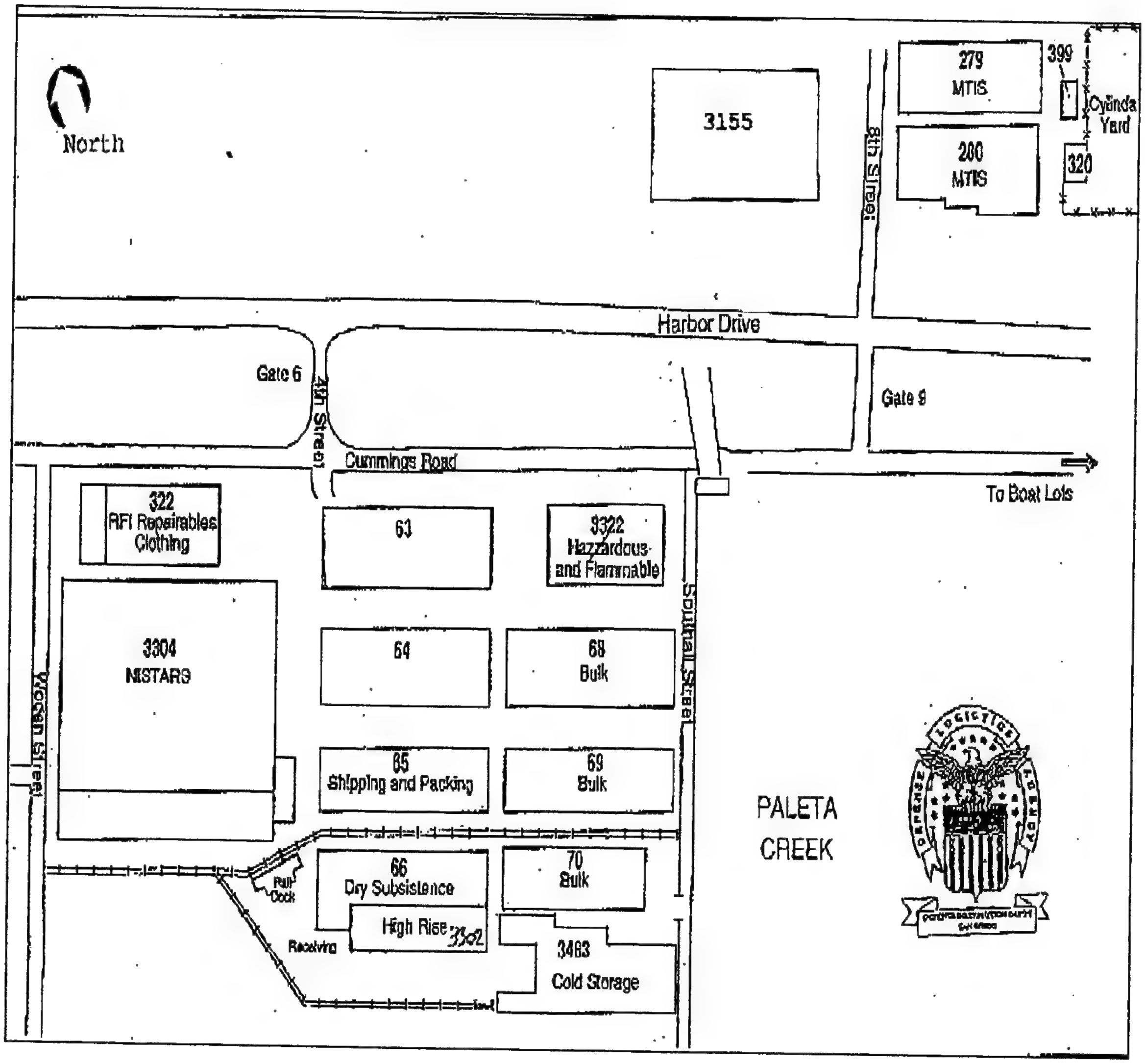

Figure 1 - DDDC Compound

2. Material Movement Plan

The two phase concept is an attempt to mitigate some of the disruption to the day-to-day business of the depot. Additionally, the two phases will allow the continued use of three of the old warehouses during Phase I and the use of the completed half of the new warehouse during Phase II. DDDC plans to use a currently unused warehouse (building #3155) for material storage during the entire

construction phase. After the new warehouse is completed, Building #3155 will be vacated and returned for use by the Navy Exchange.

Current physical distribution business of receiving and issuing material will have to continue throughout the transition to a new facility. The new DDDC warehouse will be built on the location where the old warehouses now stand. The temporary warehouse (building #3155 in Figure 1) is located across a busy four lane boulevard and is approximately 1 mile from the main depot compound.

Because of the distance and traffic, picking costs will be much higher for material stored in the temporary warehouse. Additionally, building #3155 will not have any personnel assigned to it on a regular basis. Material assignment decisions involving building #3155 must consider the higher transportation and labor costs.

The entire construction project will last approximately two years. During this time, the material stored in the old buildings scheduled to be demolished during Phase I will have to be relocated immediately, and the material stored in the remaining old buildings will have to be relocated no later than the beginning of Phase II. The temporary nature of the warehouse situation might also be a consideration when assigning material.

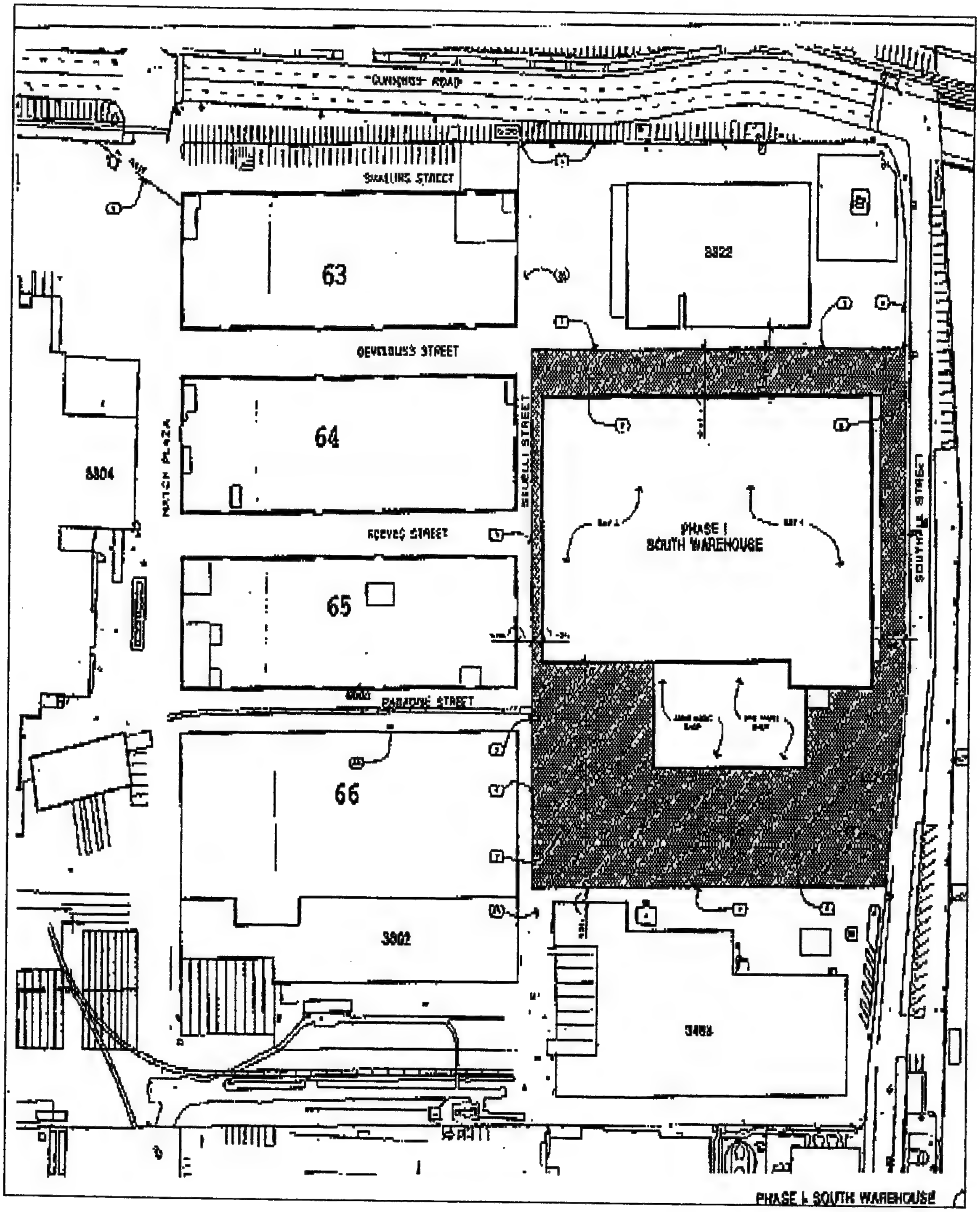

Figure 2 - Phase I Facility Layout

Building #65 is the present location of the shipping and packing operation and does not house any stowed material. The shipping and packing operation is scheduled to remain in this facility until Phase II when building #65 is torn down. During Phase II, the shipping and packing operation will be relocated to building #66 (See Figure 2).

Virtually all of the material in building #64 is sheet metal and SUBSAFE/Level 1* material. A storage facility is being constructed for these items at a distant warehouse (North Island). DDDC plans to use the vacant building #64 for Depot Support Division office space (McMillion, 1996). Therefore, we consider neither the material nor the warehouse space of building #64.

During Phase I the material in three warehouses (#68, #69, #70) must be relocated. This material can be moved into only two buildings - building #3155 and building #63. The former is vacant but the latter is filled with material. Depot managers must decide what items to assign to buildings #63 and #3155 during Phase I and in what quantities they should be stocked.

D. PURPOSE

We show how to determine which SKUs should be assigned to each warehouse and in what quantities. We test four material assignment and allocation strategies (Assign Similar Material Together, Assign by Popularity, Equal Time Supply, and Economic

* SUBSAFE/Level I material refers to special material for nuclear submarines.

Assignment Quotient) using data gathered from DDDC and recommend a strategy for DDDC based on the mix of material and the length of time the temporary warehousing situation will exist.

II. MATERIAL ASSIGNMENT AND ALLOCATION AT DDDC

A. SPACE MANAGEMENT

The essential function of a distribution center is to receive bulk shipments, store them for quick retrieval, retrieve and sort requested SKUs, and ship them out to customers. As the demand for warehouse space increases, depot managers must find better ways to utilize their space and avoid congestion that prevents timely, error-free product availability.

1. Forward-Reserve Areas

Many individual distribution facilities manage warehouse space by configuring the warehouse with a *forward* and *reserve* area. The forward area is typically a section of high-throughput flow racks or carousels. Reasons for establishing the forward and reserve areas vary among different organizations, but the main consideration is throughput requirements.

All SKUs can be assigned a reserve or bulk location, but only a selected group of SKUs can be assigned a forward location. One way to achieve higher throughput in the forward area is to locate it close to the input/output activity*, thus reducing the travel time required to retrieve items in that area.

If an SKU is assigned to the forward area, all picks for that item are executed in the forward area. The picks for SKUs not assigned to the forward area take place in the reserve area. When

* The input/output activity for a Defense Distribution Depot is the shipping and packing operation.

inventory of an SKU assigned to the forward area reaches a restocking level, an *internal replenishment* is executed from the reserve area (Frazelle, et al, 1994, p.44).

While this strategy does require the additional cost of replenishment, it can dramatically increase pick rates (Distribution Warehousing, 1994). The cost of the internal replenishment must be compared to the benefit of the increase in pick rate.

The picking cost in the reserve area is generally much higher than the picking cost in the forward area because of the increased distance that order pickers must travel to get to the reserve area locations. Therefore, depot managers can reduce order picking costs by assigning SKUs to the forward area. As the number and quantities of SKUs assigned to the forward area increase, the warehouse space designated as "forward" also increases. Eventually the size of the forward area will become so large that picking productivity suffers, thereby defeating the purpose of having a forward area (Frazelle and Hackman, et al, 1994, p.44). As long as the savings realized by picking out of the forward area is greater than the restock cost, an item should be considered for assignment in the forward area.

The quantity of an SKU in the forward area is also important: if depot managers allocate too small a quantity to the forward area, the demand for the SKU may require such frequent restocking from the reserve area that total restock costs will exceed the reduction in picking costs.

2. *Forward-Reserve Area Application to DDDC*

Most distribution centers designate a forward and reserve area for assignment-allocation decisions within a single warehouse. DDDC, however, must make material assignment decisions between entire warehouses. This presents the forward-reserve problem on a much larger scale, thereby magnifying the travel time and labor costs associated with order and internal replenishment costs from the reserve area.

Since building #63 is closer to the shipping and packing operation, it is a natural choice for the forward area. Building #3155 would then serve as the reserve area. Since the volume of building #63 is a constant, we do not need to determine the size of the forward area.

3. *Forward and Reserve Areas at DDDC are Temporary*

Previous work on the forward-reserve problem (Hackman and Rosenblatt, 1990; Hackman and Platzman, 1990) ignores the fixed cost of rewarehousing to establish the recommended product layout. This cost was assumed to be negligible when compared to overall picking costs in the long run. In our problem, however, we must consider the temporary nature of the forward and reserve warehouses, since this will make fixed rewarehousing costs significant.

For example, assume that DDDC has access to building #63 and building #3155 as the forward and reserve areas for only one day. The costs of rewarehousing the stock would far outweigh any savings from the long term benefits of anticipated demand and savings from

order picking. Clearly, when the forward and reserve areas are temporary, the rewarehousing costs should be a factor in the material assignment-allocation decision.

At DDDC, the entire construction project is scheduled to last two years. Of the three buildings not being torn down in Phase I (buildings #63, #64, #65), the material in building #64 is being moved to North Island, and building #65 consists of the shipping and packing operation. Only building #63 will remain without any rewarehousing.

It is DDDC's intention to move all the material out of building #63, regardless of the results of this study. Because of this unique circumstance, we consider the costs associated with the initial rewarehousing effort as fixed, and therefore ignore them.

The reserve area warehouse (building #3155) will be used only temporarily, during the two phase construction period. This building will remain unmanned throughout the time it is used by DDDC. Any activity associated with the reserve area (order picking or internal replenishment) will require dispatching a worker from another activity (such as building #280) to unlock building #3155.

The forward warehouse (building #63) will be torn down after Phase I, but the material in this warehouse will be relocated next door to the partially completed new facility. The shipping and packing operation will also be torn down after Phase I, but will be relocated in the main DDDC compound area in building #66, which will be vacant at that time. The material in the reserve warehouse will remain until the end of the entire construction project when

it can be permanently assigned to stowage locations in the new facility.

B. ORDER PICKING

1. General

Order picking can be defined as removing material from storage for customer orders. Pick costs are affected by the material retrieval system and the order picking method. This activity represents between 55%-65% of all operating costs in a typical warehouse (see Figure 3) (Tompkins, 1996, p.435).

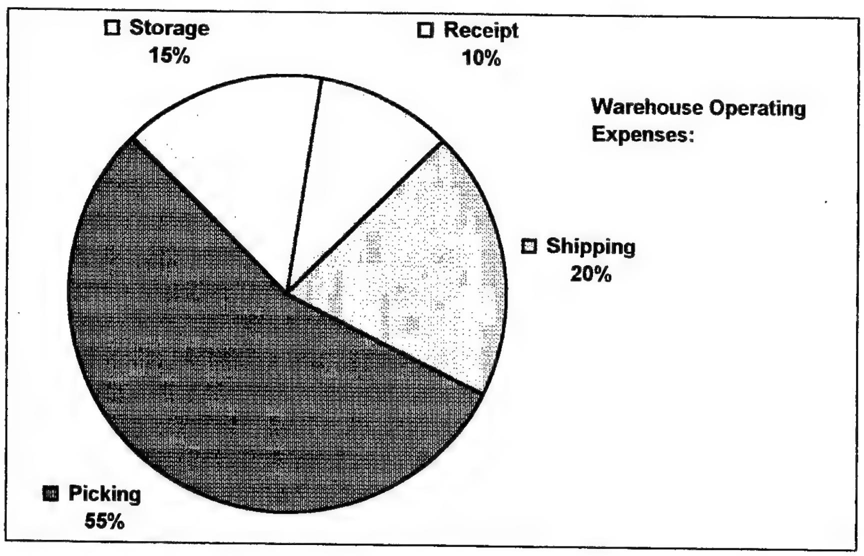

Figure 3 - Typical Breakdown of Warehouse Operating Expenses

Forward picking, reserve picking, and replenishment labor are the three components of cost in a depot's order picking operation. In non-mechanized or manual order picking, each worker is given a

pick sheet that lists the SKUs to be picked, in what amounts, and where they can be found.* Three order picking strategies are:

- **Strict order picking** - Each worker completes one order at a time. Although travel time may not be efficient because of backtracking in the same area, order integrity is maintained.
- **Batch picking** - Each worker picks SKUs for several orders simultaneously, sorting while picking. Travel time per SKU is reduced, but since order integrity is not maintained, an additional sorting step is required.
- **Zone** or **Wave picking** - The warehouse is divided into zones. Each worker is tasked with making picks that have been grouped into the same zone. Each worker travels less within the zones, but an additional sorting step is still required.

2. Order Picking in Forward Area at DDDC

Most Defense Distribution Depots have some type of automated system for picking the fastest moving SKUs. The automated system at DDDC, a system called NISTARS†, is located in building #3304 (See Figure 1).

The criterion for assignment to the mechanized NISTARS warehouse at DDDC is based mainly on the SKU's demand. An SKU with high demand may get assigned to the non-mechanized warehouse, however, if its shape or volume is not appropriate for automated storage and retrieval. Material that has a hazardous material

* Pick sheets at DDDC are displayed on a hand held computer operated by each order picker.
† NISTARS (Navy Integrated Storage, Tracking, and Retrieval System) is an automated material handling system that has an extensive database on material handled at the depot.

coding, or is identified for a special program such as SUBSAFE/Level 1 material is also assigned to a non-mechanized warehouse (McMillion, 1996).

All of the material in the six warehouses affected by the DDDC rewarehousing project are stowed in manual (or non-mechanized) storage. The non-mechanized SKUs represent only about 20% of the total DDDC inventory (Adams, 1996). This group of SKUs represents the relatively "slow movers" or odd sized items at the distribution depot.

Order pickers are assigned to each building on the main DDDC compound which represents their picking zone. Hand held computers instruct them where to locate the incoming pick requests and how many of each SKU to pick. It is DDDC's policy to have each order picker conduct batch picking by completing up to twenty picks per trip. Although this does not mean that workers wait to accumulate twenty picks before initiating a trip, twenty picks per trip is the most common batch size (McMillion, 1996).

C. MATERIAL VOLUME DATA

The volume of each SKU can be an important factor when making assignment and allocation decisions. The physical size of an SKU can affect not only the quantity allotted to the warehouse, but also the number of other SKUs assigned to the warehouse.

1. General

Volume data for non-mechanized material is not tracked at the depot level for DLA material. Automated systems, such as NISTARS,

contain cubic feet data for SKUs being handled by the automated system only. The main reason the Defense Distribution Depots do not track volume data is the expense associated with obtaining it. DDDC had the opportunity to include this piece of information in the UADPS* database but opted not to because of the cost (Yelda, 1996).

Prior to DLA taking control of all the Defense Distribution Depots, the original depots tracked individual material volume data in a database called DWASP (DLA Warehouse and Shipping Procedures) (Weeks, 1996). This information can be obtained from DORA (Defense Logistics Agency Operations Research and Economic Analysis Support Office). Unfortunately, this database is limited to old DLA items and does not include the numerous items at DDDC that are unique to the Navy.

Even when volume data is obtained for a Defense Distribution Depot, either through a database or manual means, it can be unreliable. Because cubic feet and weight data are not required fields when an SKU is assigned an NSN, the accuracy of cube dimensions in any database is suspect. DDDC personnel estimate that only 10-15% of the material in the non-mechanized buildings have any type of volume data (McMillion, 1996). Although each of the item managers do have access to volume data for material under his or her responsibility, this measurement does not always correspond to the actual measurements of the material when it is received by the depot. Repackaging or consolidation can make it possible for

* UADPS (Uniform Automated Data Processing System for Stock Points) is the information system used for management and inventory control at many Defense distribution depots.

two or more SKUs with identical NSNs to have different package dimensions and volumes.

The various information systems that exist throughout DLA's depots are highly fragmented. Each of the services has unique software to automate the distribution warehouses and track applicable data (NISTARS is the Navy's system). Distribution Standard System (DSS) is a soon-to-be-implemented consolidated DLA information system for all Defense Distribution Depots. This will standardize the information and make it accessible in a common format. DSS is scheduled to contain volume data for all material in the DLA physical distribution system, both mechanized and non-mechanized. Although DSS is scheduled to be implemented over the next couple of fiscal years, capturing all the volume data may take much longer.

Presently, when a major rewarehousing situation arises at DDDC (as well as other depots), the depot typically organizes a "sizing team" to manually measure the material (McMillion, 1996). The team can then make material assignment decisions based on the physical characteristics of the material and the available storage room.

2. Volume Data for DDDC Material

We obtained volume data by utilizing a group of Naval Reservists. They formed a sizing team and collected dimension data on recording sheets (see Figure 4) by manually measuring the outside package of each SKU with a tape measure.

Defense Distribution Depot, San Diego

BLDG	Location	NSN	Bal	Length	Width	Height	Unit Qty Per Pack	Bulk or Rack	Remarks
763	763089151	7910 012324515	78	12	6	6	1	B	
763	763093061	0105 LF0083600	18	18	15	9	1	B	
763	763093081	7520 007285761	60	15	12 1/2	9	1	B	
763	763093091	7530 002883994	3347	15 1/2	12 1/2	10	25	B	
763	763093121	0105 LF0193400	352	13	10	5 1/4	1	B	
763	763093141	6240 002865254	4125	19 3/4	12 1/2	8 1/2	1	B	
763	763093151	6110 011153353	23	16	15 1/4	6 3/4	1	B	
763	763099151	6515 011498842	27	26	16 1/2	7	4	B	
763	763099151	0116 LF0510025	0						No match
763	763099151	6415 012679661	1144	15 1/4	12	8	1	B	
763	763099151	6515 011498843	64	26	14	7 1/2	4	B	
763	763100061	7350 012636700	167	20 3/4	9 1/2	21	1	B	
763	763100071	7530 010336891	65	17 3/4	11 3/4	10	1	B	
763	763100111	7530 001817175	112	17 3/4	14 1/2	10 1/2	1	B	
763	763100121	6240 001522987	5459	49 1/4	10	8 3/4	1	B	
763	763100151	7010 012019916	31	31 1/2	17 1/2	15	1	B	
763	763104111	4240 011084171	173	24 1/2	16 1/2	9 1/2	1	B	
763	763104121	7920 007218884	34	19	14 1/2	14 1/2	1	B	
763	763108011	7920 002248728	678	76	14 3/4	4	1	B	
763	763108041	6240 001522993	6487	25	10 1/4	8 1/4	1	B	

Sheet1

Page 3

Figure 4 - Volume Data Collection Sheet

When an SKU was not in the location listed on the recording sheet, a team member performed a search on his hand held computer that had locations for all SKUs from the UADPS database. If an SKU did not have a location in the computer, then the SKU was out of stock and marked "no match".

We expected that some SKUs would have been recently issued or would be awaiting stock replenishment, and therefore would have a zero balance. When the sizing team measured the on hand material, about 15% of the material had zero balance. Since DDDC has recent order picking data on these SKUs, they can be designated as NIS (not in stock) rather than NC (not carried). We included these items for that reason.

We assigned cube values to the NIS SKUs based on the data collected on the 85% of SKUs that were in stock. Figure 5 shows the distribution of cube data for the 1,204 items for which data was collected. The median size is 1.37 cubic feet with the distribution decreasing in an exponential fashion. We wanted to use a cube number for the NIS SKUs that was larger than average size, because we felt it better to assign too much stowage space for an SKU and have extra room in the forward area, rather than to risk running out of available forward stowage space. At the same time, we did not want to penalize an SKU for being NIS by applying too large a volume, thereby preventing its assignment or decreasing its allocation to the forward area. We assigned a volume of four cubic feet to NIS items since 80% of all items had a cube less than or equal to this amount.

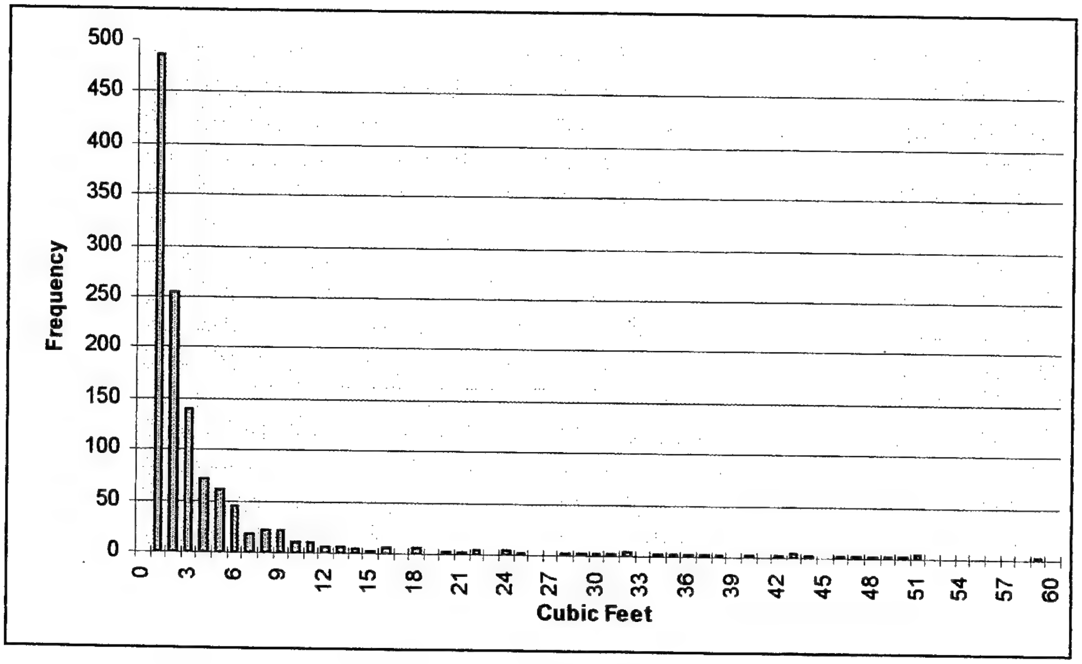

Figure 5 - Histogram of Material Volume Data (CU FT)

D. SCOPE OF FORWARD-RESERVE PROBLEM AT DDDC

1. *Material Considered for Models*

At DDDC, the material that must be relocated, whether to the forward area or the reserve area, includes all SKUs in buildings #63, #68, #69, and #70. This represents over 9,000 SKUs of material. These buildings have a combined storage capacity of 1,031,652 ACF* (362,388 ACF; 161,940 ACF; 225,288 ACF; and 282,036 ACF respectively). The reserve area, building #3155, has 1,000,000 ACF (40,000 sq. ft with 25 ft height) of bulk and rack stowage capacity. The reserve area is therefore large enough to absorb

* Attainable Cubic Feet (ACF) is the GCF (gross cubic foot) less allowances for aisles, structural loss and support space.

nearly the entire rewarehousing stowage requirements of all the buildings being torn down.

To reduce the data collection requirements for the 9,071 SKUs, we arranged SKUs in order by frequency of demand over the past year (see Figure 6).

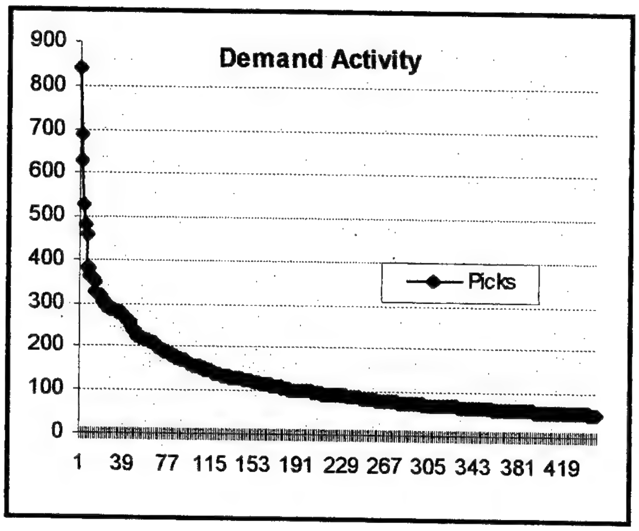

Figure 6 - Distribution of SKUs by Popularity

We include all SKUs that have an average demand of at least one pick per month. This captures 1,461, or 16%, of the most popular SKUs (see Table 2).

SKUs with ≥ 1 pick per week	**465**	**5%**
SKUs with ≥ 2 picks per month, but < 1 pick per week	**489**	**5%**
SKUs with ≥ 1 pick per month, but < 2 picks per month	**507**	**6%**
SKUs with ≥ 1 pick per year, but < 1 pick per month	**3,440**	**38%**
SKUs with zero picks	**4,170**	**46%**
Total SKUs	9,071	100%

Table 2 - SKU Popularity in Buildings #63, 68, 69, 70 Over Last 12 Months

2. Assumptions

The following assumptions apply to the strategies we use to solve the assignment-allocation problem at DDDC:

1. Monthly demand is constant.
2. The material handling cost to complete a customer request (either a pick or an internal replenishment) is independent of the size of the SKU and is based entirely on the labor cost for the time it takes to complete the action.
3. The material handling cost to complete an internal replenishment is equal to the cost of completing a pick from the reserve area since picks from the forward and reserve warehouses are done in the same quantities.
4. The on hand inventory in the reserve area is always sufficient to accommodate any internal replenishment.
5. Time spent picking SKUs is the same, whether it is done in the forward or reserve area; only the travel differs.
6. All material is handled through non-mechanized procedures.
7. Picks are made in units only. The majority of customers that DDDC serves are U.S. Navy ships. These activities are ordering material for immediate issue or to replenish on board stock that has reached a restocking level. Order quantities are normally in units for these activities.
8. The restocking level that initiates an internal replenishment for SKUs assigned to the forward area is zero.

E. MATERIAL ASSIGNMENT AND ALLOCATION STRATEGIES

Several variables associated with material being stocked in warehouses at a distribution center can affect the manager's material assignment and allocation strategy, such as: material type (sheet metal, medical supplies, etc.); size (nuts and bolts to aircraft carrier propellers); type of storage (bulk, rack or bin) and order picking activity (slow and fast moving SKUs). We discuss four common strategies available to the depot mangers at DDDC.

1. Assign Similar Material Together

Depots can benefit from grouping similar SKUs if they have special handling or storage requirements, such as hazardous material. DDDC currently uses this strategy for material assignment to non-mechanized warehouses. An SKU is allocated in its entirety to a single warehouse. For example, the material in building #64 (sheet metal and SUBSAFE/Level I material) will remain grouped together, regardless of any potential pick cost reductions, because of their handling and stowage requirements.

During the construction period at DDDC, applying the Assign Similar Material Together strategy consists of leaving the material in building #63 (the forward area) in its present location.

All SKUs associated with paper and medical supplies that presently fill building #63 are assigned to the forward area by leaving them in place. All the material in the buildings being torn down (buildings #68, #69, #70) remain grouped together as they are now but are assigned to the reserve area (building #3155).

2. *Assign by Popularity*

In the distribution of SKUs, a small percentage of the stock represents a majority of the total order picking activity (Frazelle, Dec. 1990, p.60). A common strategy is to apply Pareto's Law, or the A-B-C concept which states: (Ackerman, 1990, pp. 279-280)

- Approximately 80% of a warehouse's dollar throughput is typically attributed to 20% of the SKUs (A items).
- Approximately 15% of a warehouse's dollar throughput is typically attributed to 40% of the SKUs (B items).
- Approximately 5% of the warehouse's dollar throughput is typically attributed to 40% of the SKUs (C items).

This strategy separates the SKUs into three categories - A, B, and C. Category A material consists of the top twenty percent of SKUs as sorted by order picking frequency over the past year. Once identified, the category A SKUs are assigned to the forward area. Category B and C material is assigned to the reserve area. Consequently, the most popular SKUs are assigned to storage locations in the forward area. *

3. *Equal Time Supply*

In the equal time supply approach, each SKU is assigned enough space in the forward area to accommodate a quantity sufficient for a particular length of time. For example, consider

* Note that the group of 1,461 SKUs considered for assignment to the forward area closely corresponds to the 80/20% split of the Pareto principle.

SKUs A and B with an average demand of 12 and 48 picks per year. Under the Equal Time Supply strategy for two years, a depot manager would allot space in the forward area for 24 units of SKU A and 96 units of SKU B.

The maximum time supply that can be allotted is dependent not only on the demand for each SKU, but also on its size, and the size of the storage space in the forward area. At DDDC, the size of the forward warehouse is the ACF of building #63 (362,388 cubic feet).

4. Economic Assignment Quotient

This strategy uses a heuristic procedure to solve the assignment-allocation problem for a distribution center with a forward and reserve area within a single warehouse. The model was successfully tested by Hackman and Rosenblatt with data gathered from a Defense Distribution Depot.

The allocation decision, or how much space should be allotted to each SKU assigned to the forward warehouse, is made by calculating the net benefit of the trade-off between the savings from picking the SKU in the forward area and the associated cost of restocking the SKU from the reserve area.

The model suggests that the material should be assigned and allocated according to a simple ratio which depends only on the characteristics of the items and is independent of warehouse parameters. The ratio, called the *Economic Assignment Quotient (EAQ)*, transforms the assignment-allocation decision into a simple ranking problem.

III. APPLYING THE MODELS

In this chapter, we determine the total cost of operating under different material assignment and allocation strategies. The total cost for each strategy is the sum of the three variable order picking costs: picking from the forward warehouse, picking from the reserve warehouse, and internal replenishments from the reserve warehouse to the forward warehouse. We ignore a fourth fixed cost of picking from the reserve warehouse for the 7,610 SKUs that are not considered for assignment to the forward warehouse.

A. PARAMETER DEFINITIONS

While each strategy may use different variables that emphasize various characteristics of the material, the picking costs are determined with the same parameters:

p_i (picks of SKU i per year): All SKUs in our data selection have an average demand of at least one pick per month over the past year. We extracted this data from the NISTARS database at DDDC.

v_i (volume of SKU i in cubic feet): The volume data received from DDDC represents the cubic feet of the exterior *package* in which the individual SKU is stored in the DDDC warehouse. Inside this package there could be many individual items. It is the entire package, however, that consumes the storage space in the warehouse. We convert the package volume into a units volume by dividing the package volume by units per package.

d_i (annual demand for SKU i in cubic feet): We express this as:

$$d_i = p_i v_i \quad . \qquad \mathbf{1}$$

V (attainable storage space in the forward warehouse in cubic feet).

T (length of time that the forward-reserve configuration will exist in years): For DDDC, the forward-reserve configuration will exist during the construction of the new facility, estimated at two years.

c_f (cost of picking from the forward warehouse in $/pick):

The pay grade of the average order picker at DDDC is WG-5, Step 5. Factoring in an average 11% for fringe benefits, the hourly wage for a DDDC order picker is $13.12. [1] Time spent traveling to the picking location is the significant variable cost between the forward and reserve warehouses. Picking from the forward warehouse requires a short walk or ride in a forklift into building #63. Once an SKU is picked, the worker will deliver the material to the shipping and packing operation located less than a few hundred feet away in building #65. A DDDC time study indicates that it takes approximately 11 minutes to complete this action.[2] It is DDDC's

[1] 1996 Government Pay Rate Schedule for Wage Grade in San Diego.
[2] From the results of a time-motion study conducted at DDDC May 95 by Charles Smith, Analyst.

policy to have each order picker conduct batch picking by completing up to twenty picks per trip. Although this does not mean that workers necessarily wait to accumulate twenty picks before initiating a trip, twenty picks per trip is the most common batch size (McMillion, 1996). All order picking costs (forward, reserve and internal replenishment) are adjusted for the standard batch size by dividing each figure by twenty. For the DDDC data, the cost of picking from the forward warehouse is $0.122/pick.

c_r (cost of picking from the reserve warehouse in $/pick): This includes all the time necessary to obtain instructions, supplies, equipment; go to and from building #3155; issue and verify material; palletize and dispatch to the shipping and packing operation. Retrieval of an SKU from the reserve area requires transportation in a vehicle (such as a truck) to cross Harbor Drive. Since building #3155 is not manned, after obtaining the proper keys, a worker must drive through a stoplight, across the highway, pass through a gate guard and unlock the facility. The total one-way distance is approximately .75 miles. A time study conducted at DDDC revealed that the time it takes to complete this action is approximately 25 minutes.[3] For the DDDC data, the cost of picking from the reserve warehouse is $0.273/pick.

r (cost of restocking the forward warehouse by an internal replenishment from the reserve warehouse in $/pick): This action

[3] From actual measurements by DDDC Warehouse Division Staff.

requires the same travel time as picking from the reserve area, therefore, the restock cost is also $0.273/pick.

R (cost of picking, in $/yr., from the reserve warehouse for the 7,610 SKUs not considered for assignment to the forward warehouse): Let I_1 be the set of items considered for allocation into the forward area, and I_2 be the set of items not being considered. Then,

$$R = \sum_{i \in I_2} c_r p_i = \$3{,}470. \qquad 2$$

B. APPLICATION OF FOUR STRATEGIES

Using the above definitions, we apply the four material assignment-allocation strategies to the data collected from DDDC -- Assign Similar Material Together, Assign by Popularity, Equal Time Supply, and Economic Assignment Quotient.

1. Assign Similar Material Together

The costs for picking in the forward warehouse are determined by summing the costs per pick of all the 227 SKUs presently located in building #63. The costs for picking in the reserve warehouse are calculated by summing the costs per pick for each SKU that has been assigned to building #3155.

Let I_{63} be the set of items assigned to building #63. The total cost equation for the similar material model is:

$$\mathrm{TC}_{\mathrm{Sim\ Matl}} = \sum_{i \in I_{63}} c_f p_i T + \sum_{i \notin I_{63}} c_r p_i T + RT \,. \qquad 3$$

The three terms in the above equation represent the three picking costs associated with this model: picking from the forward warehouse, picking from the reserve warehouse, and picking from the reserve warehouse for the 7,610 SKUs not considered in the model.

By varying the length of time that the forward-reserve configuration exists, we can solve for the costs associated with each of the above equation terms over time. The results are in Table 3.

T (Years)	1	1.5	2	2.5	3	3.5	4
Forward Picking	$2,773	$4,160	$5,546	$6,933	$8,319	$9,706	$11,092
Reserve Picking	$15,799	$23,699	$31,598	$39,498	$47,397	$55,297	$63,196
Internal Replsh	$0	$0	$0	$0	$0	$0	$0
Reserve Picking (other 7,610)	$3,470	$5,205	$6,939	$8,674	$10,409	$12,144	$13,879
Total	$22,042	$33,063	$44,084	$55,105	$66,126	$77,146	$88,167

Table 3 - Cost Equation Results for Assign Similar Mat'l Together Strategy

Figure 7 shows a graphic illustration of each of the cost terms broken down over time for the Assign Similar Material Together strategy.

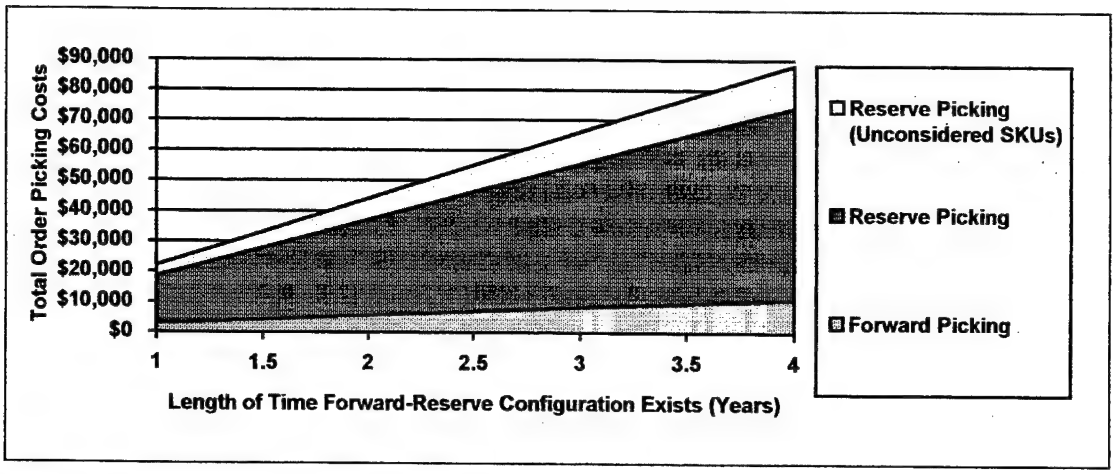

Figure 7 - Cost Breakdown for Assign Similar Material Together Strategy

The total picking costs for this model increases linearly over time. There are no internal replenishment costs because the SKUs assigned to the forward warehouse do not have dual reserve warehouse locations.

2. *Assign by Popularity*

In this model, we assign SKUs to building #63 one by one in order of picking activity. This continues until all the forward warehouse storage space is full, or until the top 20% of the SKUs have been assigned to the forward area. The 20% maximum follows the 80/20 split recommended by the Pareto concept. For the DDDC data, the material assigned to the forward warehouse (building #63) includes the first 292 SKUs.

The total cost equation for the Assign by Popularity model is given by equation 3. The costs associated with each of the equation terms over time are shown in Table 4.

T (Years)	1	1.5	2	2.5	3	3.5	4
Forward Picking	$5,668	$8,502	$11,336	$14,170	$17,004	$19,838	$22,672
Reserve Picking	$9,314	$13,971	$18,628	$23,285	$27,942	$32,599	$37,256
Internal Replsh	$0	$0	$0	$0	$0	$0	$0
Reserve Picking (other 7,610)	$3,470	$5,205	$6,939	$8,674	$10,409	$12,144	$13,879
Total	$19,189	$27,677	$36,903	$46,129	$55,355	$64,580	$73,806

Table 4 - Cost Equation Results for Assign by Popularity Strategy

Figure 8 shows a graphic illustration of each of the cost terms broken down over time for the Assign by Popularity strategy.

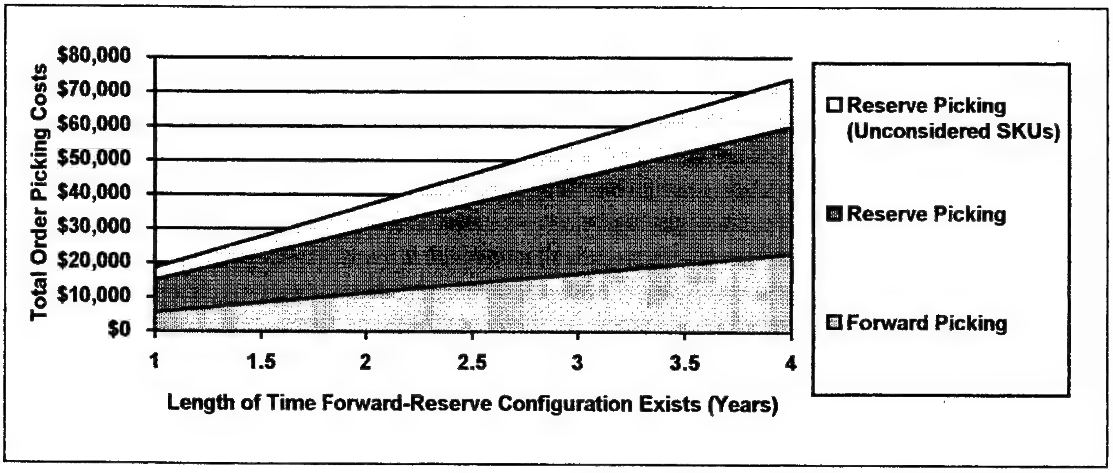

Figure 8 - Breakdown of Costs for Assign by Popularity Strategy

The total picking costs for this model increase linearly over time. There are no internal replenishment costs because the SKUs assigned to the forward warehouse do not have dual reserve warehouse locations.

The forward picking costs of this strategy are greater because the majority of the picking activity is being done from the forward warehouse. Likewise, the lower picking activity in the reserve warehouse for this strategy translates to lower reserve picking costs.

3. Equal Time Supply

This model assigns all 1,461 SKUs to the forward warehouse in quantities that represent stock sufficient for a specified length of time t. The length of time t is determined by finding the time supply of stock for each SKU that allocates all of the forward warehouse storage space. For the DDDC data, the time $t = 2.1$ years.

Therefore, the quantity z_i that each SKU is allotted to the forward area is

$$z_i = p_i t \ . \qquad \textbf{4}$$

Since all of the SKUs are assigned to the forward warehouse, all of the order picking costs will be from the forward area. The total order picking cost is the sum of all the forward warehouse order picking costs and the sum of all the internal replenishment costs.

The total cost equation for the Equal Time Supply model is:

$$\begin{aligned} \mathrm{TC}_{\text{Equal Time}} &= \sum_i c_f p_i T \quad \text{for } T \le t \text{, and} \\ &\sum_i c_f p_i T + c_r p_i (T - t) \quad \text{for } T > t \end{aligned} \qquad \textbf{5}$$

The costs associated with each of the equation terms over time are in Table 5.

T (Years)	1	1.5	2	2.5	3	3.5	4
Forward Picking	$9,826	$14,738	$19,651	$24,564	$29,477	$34,391	$39,302
Reserve Picking	$0	$0	$0	$0	$0	$0	$0
Internal Replsh	$0	$0	$0	$8,804	$19,810	$30,815	$41,820
Reserve Picking (other 7,610)	$3,470	$5,205	$6,939	$8,674	$10,409	$12,144	$13,879
Total	$13,295	$19,943	$26,591	$42,042	$59,695	$77,348	$95,001

Table 5 - Cost Equation Results for Equal time Supply Strategy

Figure 9 shows a graphic illustration of each of the cost terms broken down over time for the Equal Time Supply strategy.

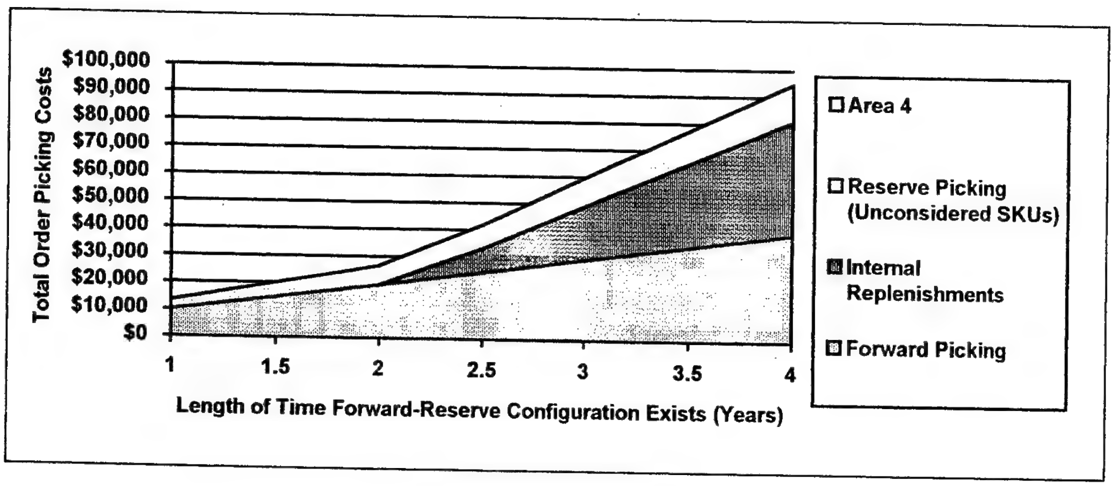

Figure 9 - Breakdown of Costs for Equal Time Supply

There are no reserve picking costs or internal replenishment costs for the first two years. After two years, however, the costs for internal replenishments begin, driving up the total costs dramatically. Because total order picking costs do not increase linearly over time, depot managers should consider not only the length of time that the forward-reserve area configuration will exist, but also the uncertainly associated with that time.

4. Economic Assignment Quotient

The EAQ procedure has four steps:

1. Rank all SKUs by EAQ according to $\frac{p_i}{\sqrt{d_i}}$. **6**

2. Select an ordered subset of SKUs, first choosing SKU 1; then choosing SKUs 1, and 2; then choosing SKUs 1, 2, and 3; and so on. This is the assignment step.

3. Calculate the allocation for the SKUs in each subset according to:

$$z_i = \left(\frac{\sqrt{d_i}}{\sum_j \sqrt{d_j}} \right) V \qquad \textbf{7}$$

Where z_i is the cubic feet of SKU i to be assigned to the forward area. This is the allocation step.

4. Calculate total net benefit of each subset by:

$$\sum f(z_i), \text{ where}$$

$$f(z_i) = \left\{ sp_i - r\left(\frac{d_i}{z_i}\right) \text{ if } z_i > 0;\ 0, \text{otherwise.} \right. \qquad \textbf{8}$$

s is the savings per pick in the forward area in \$/pick ($s = c_r - c_f = \$0.174$ per pick).

We want to store the right SKUs in the right amounts so we choose the subset with the maximum net benefit, where

$$\sum_i z_i \leq V \text{ , and}$$

$$z_i \geq 0 \text{ .}$$

The subset of SKUs having the greatest net benefit is assigned to the forward area. For the DDDC data, the greatest net benefit occurs when all 1,461 SKUs are assigned to the forward warehouse.

We assign to the forward warehouse the quantity

$$b_i = \left\lceil \frac{z_i}{v_i} \right\rceil \text{ of SKU } i \text{ .} \qquad \mathbf{9}$$

When the forward warehouse balance of an SKU reaches zero, the forward warehouse is replenished with the full quantity allotted to that SKU. Therefore, b_i also represents the restock quantity of each SKU when an internal replenishment is initiated.

Total cost for this model is the sum of the forward picking costs, the reserve picking costs, and the costs of any internal replenishments. The total cost equation for the Economic Assignment Quotient model is

$$\mathrm{TC_{EAQ}} = \sum_i c_f p_i T + \left[\sum_i r p_i \text{ if } T p_i > 0; \text{ 0 otherwise} \right] + RT \text{ .} \qquad \mathbf{10}$$

The costs associated with each of the equation terms over time are in Table 6.

T (Years)	1	1.5	2	2.5	3	3.5	4
Forward Picking	$9,826	$14,738	$19,651	$24,564	$29,477	$34,390	$39,302
Reserve Picking	$0	$0	$0	$0	$0	$0	$0
Internal Replsh	$2,117	$5,479	$8,959	$13,728	$17,354	$19,625	$21,520
Reserve Picking (other 7,610)	$3,470	$5,205	$6,939	$8,674	$10,409	$12,144	$13,879
Total	$15,412	$25,422	$35,550	$46,966	$57,240	$66,159	$74,701

Table 6 - Cost Equation Results for EAQ Strategy

Figure 10 shows a graphic illustration of each of the cost terms broken down over time for the Economic Assignment Quotient strategy.

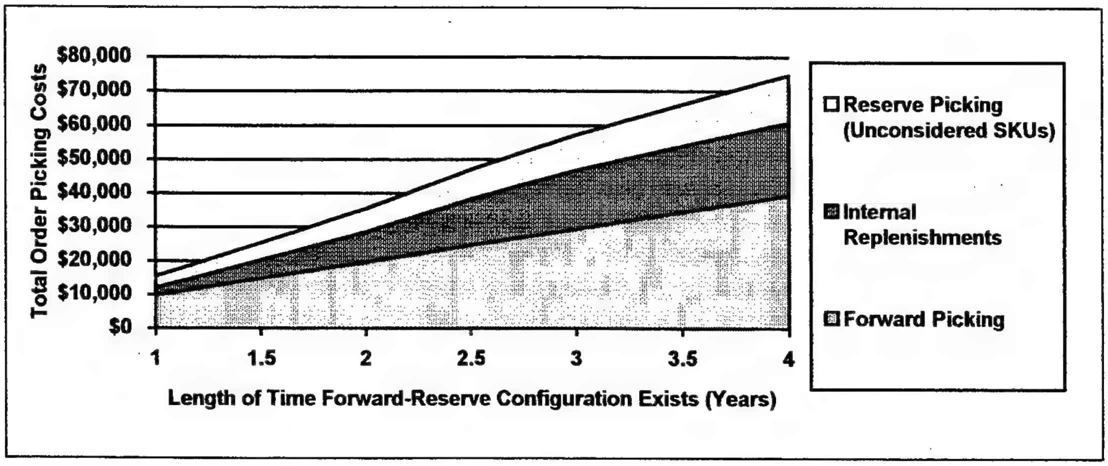

Figure 10 - Breakdown of Costs for Economic Assignment Quotient Strategy

The total picking cost for this model increases linearly over time. There are no costs associated with picking from the reserve warehouse for the 1,461 SKUs assigned to the forward warehouse because, if an SKU is assigned to the forward warehouse, all picks for that item are executed in the forward warehouse.

C. COMPARISON

A summary of the total picking costs for each strategy is shown in Figure 11. The summary shows the best material assignment allocation strategy will vary over time depending on how long the forward-reserve configuration exists.

The Equal Time Supply strategy has the lowest total cost until year three (see Figure 11), when the internal replenishment costs begin (see Figure 9), and the total costs for this strategy increase dramatically.

The Assign Similar Material Together strategy is the poorest strategy for lowering picking costs because it does not consider either the picking activity characteristics or the physical size of the material.

Because both the EAQ and the Assign by Popularity strategies *do* consider the picking activity characteristics of material, they have the lowest total costs in the long run.

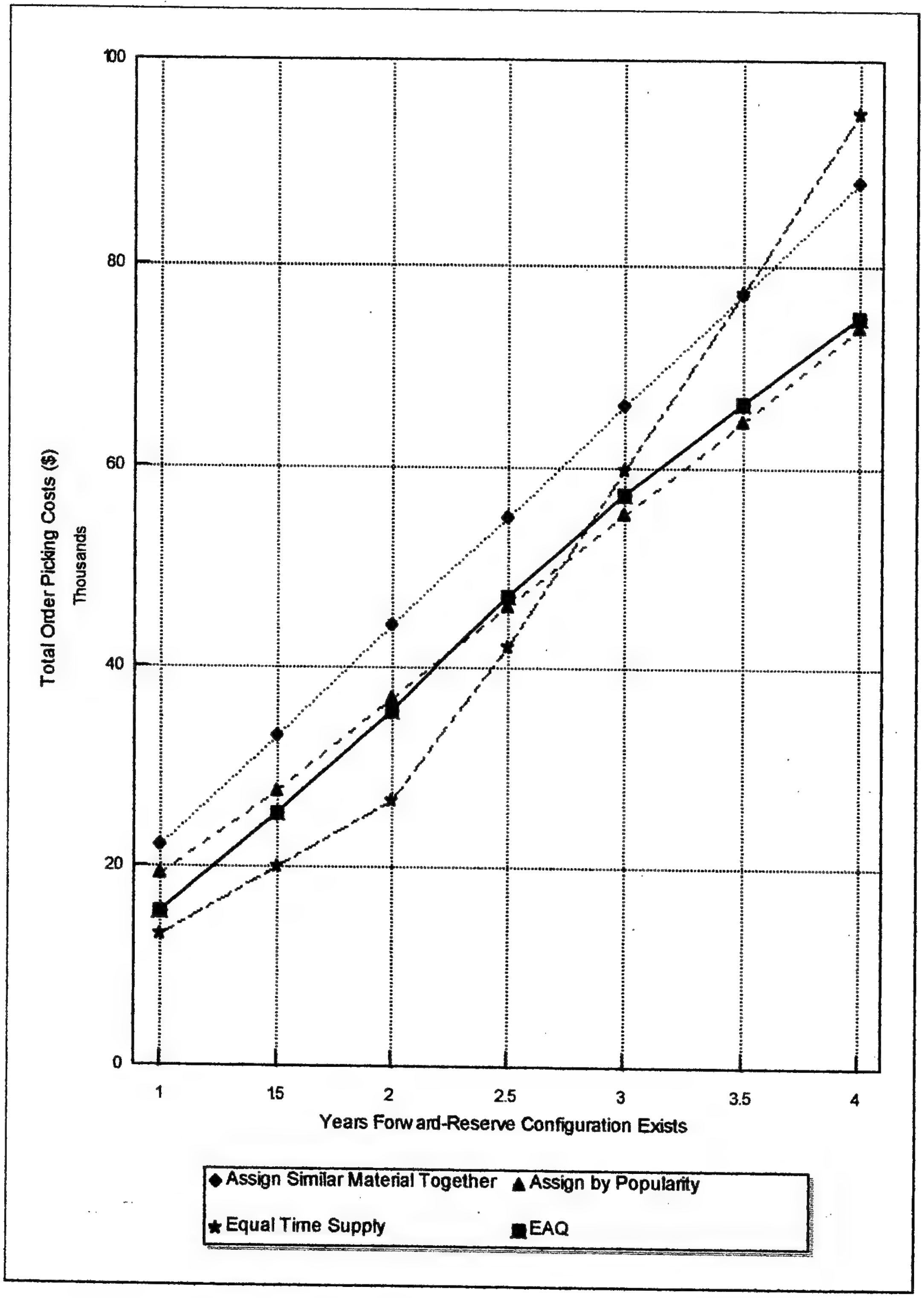

Figure 11 - Summary of Total Picking Costs for All Strategies

IV. CONCLUSIONS AND RECOMMENDATIONS

We have shown how one depot can decrease overall picking costs and increase throughput by establishing a forward warehouse from which to pick the fastest moving SKUs. We have also shown how to select SKUs for that warehouse and determine their stock levels.

A. CONCLUSIONS

Based on the model results, we draw three conclusions.

1. Equal Time Supply is the best strategy if rewarehousing takes two years or less.

The results show that if a time constraint is placed on how long the forward-reserve configuration will exist, it can influence the relative outcomes of some strategies. The Equal Time Supply strategy is the most cost effective strategy, as long as the length of time the forward-reserve configuration exists does not exceed the length of the time supply that is stored in the forward warehouse. Prior to this time, there are no internal replenishment costs. Because all the SKUs have a forward warehouse assignment, there are never any reserve picking costs. The only costs during this time are the forward picking costs.

Once this threshold has been crossed, internal replenishment costs increase dramatically. In our study, one year after the threshold was crossed, the Equal Time Supply strategy went from the lowest cost strategy to the third of the four strategies (see Figure 11). Therefore, if it is likely that the forward-reserve

configuration will exist for more than 2.5 years a different strategy might be more suitable, such as EAQ or Assign by Popularity.

2. A long term forward-reserve configuration favors the EAQ strategy.

By allowing the different strategies to stabilize over the long term, we discount the temporary, short term nature of the DDDC scenario. Both the EAQ and the Assign by Popularity strategies have lower total picking costs over the long term (see Figure 12). Although the long term total picking costs of the Assign by Popularity strategy is competitive with the EAQ strategy in the DDDC data, this may be misleading for other scenarios. The Assign by Popularity strategy, unlike the EAQ strategy, does not consider the physical characteristics of each SKU. In the DDDC data, the fastest moving SKUs also happened to be the smallest SKUs. Because of their small size, a large number of the SKUs were able to be assigned to the forward warehouse.

In a scenario with different material data, the fastest moving SKUs might also happen to be the largest SKUs. Then, the forward warehouse would fill to capacity with far fewer SKUs assigned. This would cause a dramatic decrease in forward picking and an increase in reserve picking, thus driving up overall picking costs.

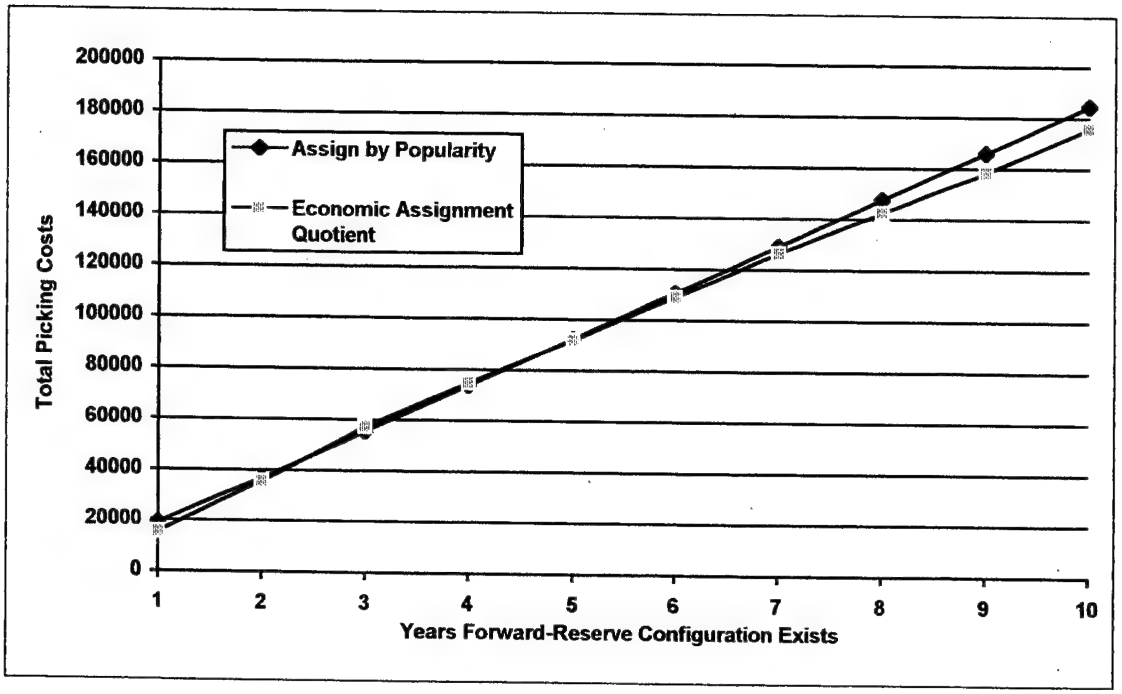

Figure 12 - Long Term Forward-Reserve Configuration

3. Assign by Popularity strategy is best if pick savings are negligible or if material volume data is not available.

The present DDDC material assignment strategy of assigning similar material together prevents the need for any internal replenishment actions. If DDDC were to implement either the EAQ or the Equal Time Supply strategy, the warehouse workers would need to be instructed when an internal replenishment is to be initiated and what quantity each SKU is to be restocked.

If the difference between the strategy with the lowest total pick costs and the Assign by Popularity strategy is negligible, the cost of training warehouse personnel might make the Assignment by Popularity strategy more suitable.

Although we were able to capture volume data for the DDDC material, all Defense Distribution Depot managers may not have the

same opportunity. Until individual SKU volume data is available in the DSS database, assigning material with the highest picking activity to the forward warehouse is a good rule of thumb.

B. RECOMMENDATIONS

1. DDDC should use Equal Time Supply strategy.

We recommend that DDDC use the Equal Time Supply strategy for their material assignment-allocation decision between buildings #63 and #3155. The construction phase is scheduled to last 2 years, which is less than the 2.1 years worth of stock that the forward warehouse will store.

Additionally, at the end of the Phase 1 (approximately one year), the forward warehouse, building #63, is scheduled to be demolished. All material left in storage at that time will have to be rewarehoused to a new location. If the construction period lasts exactly two years, as scheduled, then the forward warehouse material will be rewarehoused at the one year point to the new constructed facility. At the end of Phase II, only one months worth of material will have to be rewarehoused to its new, permanent location.

By choosing the Equal Time Supply strategy, we estimate that DDDC will save 40% in total picking costs over the present Assign Similar Material Together strategy over the two year construction period. The Equal Time Supply strategy is robust for the time period considered. If the construction project should slip two and

one-half to three years, the Equal Time Supply strategy would still be among the best strategies.

2. Track material volume data within DOD.

DoD can assist the Defense Distribution Depot managers in making smarter, more informed material assignment-allocation decisions by tracking material volume data. We encourage the implementation of the new DSS information system and the timely capture of volume data. Additionally, units per package data needs to be captured and made accessible to depot managers.

3. Further Research

We explored the forward and reserve areas as represented by different warehouses. This is a generalization of the original Hackman-Rosenblatt study which identified the forward and reserve areas as different area within the same warehouse.

We suggest expanding the forward-reserve problem to an even higher level of planning. In his testimony to the U.S. Navy House Armed Services/Readiness FY 95 Defense Authorization Subcommittee, Rear Admiral E.R. Chamberlin stated that DLA is developing a "forward depot" concept to support future contingencies or MRC (major regional conflict) operations. The forward depot is established so that DoD could position selected DLA items in-country to reduce the Services' initial mount-out costs. This forward depot could be designated the forward area and all "out-country" depots could be designated the reserve area. Such an

arrangement could lead to enhanced readiness of forward deployed forces at low cost.

APPENDIX

LIST OF ABBREVIATIONS AND ACRONYMS

ACF	Attainable Cubic Feet
AS/RS	Automated Storage and Retrieval System
BRAC	Base Realignment and Closure Commission
DDDC	Defense Distribution Depot, San Diego
DLA	Defense Logistics Agency
DSS	Distribution Standard System
DWASP	DLA Warehouse and Shipping Procedures
DoD	Department of Defense
EAQ	Economic Assignment Quotient
FRP	Forward-Reserve Problem
IG	Issue Group
JIT	Just in Time
MILCON	Military Construction
NAVSUP	Naval Supply
NIS	Not in Stock
NISTARS	Navy Integrated Storage, Tracking, and Retrieval System
NSN	National Stock Number
SKU	Stock Keeping Unit
UADPS	Uniform Automated Data Processing System for Stock Points

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